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1. Your reference — 1999P04839/GB/R76/MM/am

2. Patent application number *(The Patent Office will fill in this part)* — **9919973.9** 24 AUG 1999

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

ROKE MANOR RESEARCH LIMITED
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Patents ADP number *(if you know it)* — 56154555006

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — IMPROVEMENTS IN OR RELATING TO MOBILE TELECOMMUNICATIONS SYSTEMS

5. Name of your agent *(if you have one)* — MARGARET MACKETT

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

SIEMENS GROUP SERVICES LIMITED
INTELLECTUAL PROPERTY DEPARTMENT
SIEMENS HOUSE
OLDBURY
BRACKNELL
BERKSHIRE
RG12 8FZ

Patents ADP number *(if you know it)* — 7421878001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
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Signature M Mackett Date 24/08/1999

Margaret Mackett

12. Name and daytime telephone number of person to contact in the United Kingdom

Margaret Mackett - 01344 396808

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IMPROVEMENTS IN OR RELATING TO MOBILE TELECOMMUNICATIONS SYSTEMS

The present invention relates to improvements in or relating to mobile telecommunications systems and is more particularly concerned with synchronisation of base stations within a telecommunications system.

The UMTS terrestrial radio access (UTRA) – time division duplex (TDD) system is based on a combination of code division multiple access (CDMA) and hybrid time division multiple access (TDMA) and TDD. (UMTS is an acronym for universal mobile telecommunication system as understood by persons skilled in the art.)

The UTRA, UMTS TDD mode incorporates a combined TDD/TDMA multiple access scheme, and requires synchronisation between its base stations. Moreover the system is required to provide position information for the mobile stations. The synchronisation of base stations must be achieved at the levels of time slots, frames and multi-frames, where a multi-frame is a repeating cycle of a number of frames.

One known mechanism for synchronising the base stations is to equip each base station with a global positioning system (GPS) receiver. However, this is not always appropriate or even possible. For example, an area of deployment may be shadowed from the GPS constellation of satellites by tall buildings. For this and other reasons, alternative means of synchronising the base stations are required.

Another possible option is to synchronise the base station over the backhaul network. However, if this is implemented according to a packet protocol (for example, internet protocol (IP) or asynchronous transfer mode (ATM)), then only coarse accuracy synchronisation will be possible.

It is therefore an object of the present invention to provide synchronisation of base stations.

In accordance with one aspect of the present invention, there is provided a method of providing synchronisation between a plurality of base stations in a telecommunications system, each base station having at least one mobile station associated therewith, the base station and its associated mobile stations comprising a telecommunications cell, the method comprising the steps of:

providing a random access channel in each telecommunications cell via which a mobile station requests a resource unit; and

utilising the random access channel in one telecommunications cell to transmit a synchronisation signal to other base stations within the telecommunications system.

Advantageously, the random access channel comprises a time slot per frame.

It is preferred that the method further comprises scheduling for the utilisation of each time slot.

Advantageously, in accordance with the method of the present invention, radio transmissions in the same band of frequencies as that provided for communications with mobile stations are utilised to provide the desired base station synchronisation.

More particularly, within the UTRA TDD system, there is the provision of a random access channel (RACH) which is a single time slot per TDMA frame allocated to transmissions from mobile stations to initiate communications, usually by requesting a resource unit (time slot and CDMA code combination) for uplink usage. In accordance with the present invention, the RACH channel is utilised for both inter base station synchronisation and for mobile station position location.

In accordance with another aspect of the present invention, there is provided a method of locating a mobile station within a telecommunications cell forming part of a telecommunications system, the telecommunications cell comprising a base station and at least one mobile station, the method comprising the steps of:

determining the location of at least three base stations;

scheduling synchronisation measurements for each of the base stations utilising a random access channel;

transmitting a signal from the mobile station;

receiving the transmitted signal at each of the three base stations;

comparing the received signals with timing signals in each of the base stations; and

using the comparison at each base station to determine the location of the mobile station.

In a typical cellular deployment, the range between neighbouring base stations is roughly double the range from any base station to a station at its cell boundary. In an urban deployment, this typically leads to a path loss which is of the order of 12dB greater to the neighbouring base station than to the cell-edge mobile station. On the one hand, the base station would have a height gain advantage over a mobile station at the same location. On the other hand the base station antennas typically are constructed with a 'down tilt' intended to reduce inter cell interference. These effects will tend to cancel, making the 12dB figure a reasonable estimate for the increase in path loss.

In accordance with the invention, it is proposed to arrange for a base station at suitable times to 'steal' the RACH time slot for transmissions to other base stations. It is currently assumed that the same time slot will be used for RACH operation in all cells. Whilst this is advantageous, it is not

essential to the operation of this invention. The time for a base station to steal a RACH time slot can be determined according to the following criteria:

a) Neighbouring base stations must not steal the RACH time slot in the same frame.

b) RACH time slots must be stolen frequently enough to maintain overall base station network synchronisation to the required accuracy.

c) Schedules for RACH time slot stealing may be determined either centrally by a radio network controller (RNC) or according to sequence generators resident in the base stations. In the latter case, the sequence generators are arranged in such a way that RACH stealing schedules do not coincide in neighbouring cells. If the RNC is used, the preferred option, it can establish schedules according to this criterion. The schedules may be at regular, pseudo random or constrained random intervals.

When a base station has a schedule assigned for RACH stealing in the near future, at a suitable time it makes a broadcast transmission (probably on its broadcast control channel, BCCH) to all mobile stations affiliated to it, to instruct them that the RACH channel will be unavailable for mobile station transmissions in the forthcoming scheduled stolen RACH channel timeslot. This will clear the stolen RACH channel time slot for inter cell synchronisation usage.

Arranging for the stealing base station to silence its stations when the RACH channel is stolen will prevent unnecessary collisions on the RACH channel.

However, as described so far the neighbouring base stations will not silence their affiliated mobile stations from them making RACH transmissions. These RACH transmissions will be power controlled and it should be possible for the neighbouring base stations to receive the transmission from the base station stealing the RACH timeslot and to receive

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any RACH transmissions from their own affiliated mobile stations. However, in the case where stolen RACH timeslots are scheduled by the RNC, it is optionally possible to arrange for the neighbouring base stations to silence RACH transmissions from their mobile stations using the same procedure as described for the RACH time slot stealing.

In this way the interference to the synchronisation transmission can be substantially removed, except from distant stations. If this option is not employed then interference to the reception of synchronisation transmission in the RACH timeslot may prevent its reception. However, given the statistics of RACH traffic, a high proportion of such measurements should be received.

An alternative approach for 'stealing' RACH slots for synchronisation is to arrange for RACH slots throughout the network to be allocated to synchronisation at regular fixed intervals. In this approach, during these periods, none of the mobile stations would make RACH transmissions, and it would not be necessary to instruct the mobile stations not to make the RACH transmissions since they could determine such times for themselves. However, the base stations could transmit a simple binary signal periodically to indicate that this mode of operation applied (it would not be necessary in a network where all base stations had associated GPS receivers). In this approach, during the selected RACH time slots all base stations would be either listening for synchronisation transmissions or making them. The subset of base stations making synchronisation transmissions would change from one selected RACH time slot to the next. It would be necessary to ensure that the spread of transmissions is such that only one dominant synchronisation signal is received at any given base station in any given selected RACH time slot. The planning of these subsets

could be performed either manually or automatically according to scheme similar to dynamic channel assignment (DCA).

Within the UTRA TDD structure, each timeslot has a duration of 2560 chips less a guard period. Because the base stations are static and have accurate frequency references, it is possible to perform correlation across the entire period, affording a processing gain of about 34dB. This high processing gain serves to compensate for the increased path loss to the neighbouring cells.

Assuming that every base station sends and receives synchronisation bursts to and from its neighbouring base stations, all of the information necessary for the network wide synchronisation can be aggregated. This can be used in one of two distinct ways, either distributed or centralised.

In the distributed approach, every base station acts autonomously on the basis of the information it has received to adjust its clock timing in such a way that, given that all other base stations operate similarly, they will come into synchronisation.

In the centralised approach all base station report their results to the RNC which then computes a set of adjustments and signals them individually to the relevant base stations. Essentially, each base station measures the timing of each received synchronisation burst relative to its own timing. This can be viewed as the timing of the received burst relative to the time at which it would make its transmission. Each base station is provided with a matched filter, matched to the synchronisation code. When a burst is received, there will usually be several discrete paths. The earliest significant path will be taken to provide the timing since this is most likely to correspond to the line of sight path if there is one. The following discussion relates to the centralised synchronisation procedure, following coarse level synchronisation.

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Suppose we have a deployment of N base stations. Let the variable $L(i,j) = L(j,i)$ indicate those base stations which are able to hear each other's synchronisation transmissions. If base station i can hear base station j's transmission and base station j can hear base station i's transmission then $L(i,j) = (j,i) = 1$. Otherwise $L(i,j) = L(j,i) = 0$. Note that $L(i,i) = 0$ for all i. All relative timings are aggregated at the RNC. If base station i hears base station j's transmission with delay $d_{i,j}$ and base station j hears base station i's transmission with delay $d_{j,i}$, then the RNC computes the time differences as

$$\delta_{i,j} = d_{i,j} - d_{j,i}$$

and

$$\delta_{j,i} = d_{j,i} - d_{i,j} = -\delta_{i,j}$$

Thus $\delta_{i,j}$ is the time by which base station i's time is advanced with respect to the time of base station j.

Suppose base station i will be retarded by a compensation amount C_i which is to be computed. Following such compensation, the new timing error between base stations i and j will be given by

$$\delta'_{i,j} = \delta_{i,j} - C_i + C_j$$

If all measurements were completely accurate and consistent, we could simply solve the equations to make $\delta'_{i,j} \equiv 0$ for all i and all j.

However, given measurement errors it is better to solve for a minimum sum square error, that is,

$$\sum_{i=1}^{N}\sum_{j=1}^{N} L(i,j)\delta'^{2}_{i,j}$$

should be minimised. Expanding this gives:-

$$\sum_{i=1}^{N}\sum_{j=1}^{N} L(i,j)\left\{\delta^{2}_{i,j} + C_i^2 + C_j^2 + 2\left(\delta_{i,j}.C_j - \delta_{i,j}.C_i - C_i.C_j\right)\right\}$$

Let $M(i)=\sum_{j=1}^{N} L(i,j)$ be the number of base stations whose synchronisation transmissions base station i can hear and who can also hear base station i's synchronisation transmission. We can then express the sum square error as

$$2\sum_{i=1}^{N} M(i)C_i^2 + \sum_{i=1}^{N}\sum_{j=1}^{N} L(i,j)\delta_{i,j}^2 - 4\sum_{i=1}^{N} C_i \sum_{j=1}^{N} L(i,j)\delta_{i,j} - 2\sum_{i=1}^{2}\sum_{j=1}^{N} L(i,j)C_j$$

Now differentiate with respect to C_i and equate to zero. We obtain

$$4M(i)C_i - 4\sum_{j=1}^{N} L(i,j)\delta_{i,j} - 4\sum_{j=1}^{N} L(i.j)C_j = 0$$

Thus

$$M(i)C_i - \sum_{j=1}^{N} L(i,j)C_j = \sum_{j=1}^{N} L(i,j)\delta_{i,j}$$

We can express this in matrix notation as

$$(\mathrm{diag}(\mathbf{M}) - \mathbf{L})\mathbf{C} = \mathbf{D}$$

where $\mathrm{diag}(\mathbf{M})$ is the diagonal matrix with elements $M(i)$, $i \in \{1 \ldots N\}$ along the diagonal,

L is the matrix with elements $L_{i,j}$,

C is the vector with elements C_i, and

D is a vector with elements

$$D_i = \sum_{j=1}^{N} L(i,j)\delta_{i,j} = \sum_{j=1}^{M(i)} \delta_{i,S_j(i)}$$

where $S_j(i)$, $j \in \{1 \ldots M(i)\}$ is the set of indices of base stations to and from which base station i can send and receive sync transmissions respectively.

Let $\mathbf{A} = (\mathrm{diag}(\mathbf{M}) - \mathbf{L})$

This matrix is singular. This reflects the fact that any common value can be added to all compensation values, C_i without affecting the sum square error. A reasonable constraint to apply to the compensation values is that

their sum should be zero so as to minimise the overall drift. Thus, we have an additional equation:-

$$\sum_{i=1}^{N} C_i = 0$$

This can be reflected in the matrix equation by adding a row of ones to any of the rows in **A** to form $\mathbf{A}'$.

We can now solve the equation to obtain the compensation values. However, we can note that **A** (and therefore $\mathbf{A}'$) does not change very rapidly, if at all, since it is a function only of the base station connectivity. Thus, it may be more efficient to compute the inverse of $\mathbf{A}'$ which need only be updated infrequently. We thus obtain:-

$$\mathbf{C} = \mathbf{A}'^{-1}\mathbf{D}$$

A mobile station may need to be located within its cell. This may arise if, for example, the user makes an emergency call. Position measurements can be performed on the basis of delay measurements. A minimum of three base stations must be involved in the measurements in order to obtain an unambiguous location. This is because two dimensions of space plus time must be determined. In order for such positioning to be performed the base stations involved must be either synchronised or must know their mutual time difference to a high accuracy. The periodic updating described earlier may not provide accurate enough synchronisation for position location. According to one embodiment of the invention, the requirement for positioning initiates a set of sync measurements between the base stations involved. Before this can be done the base stations to be involved must be determined. The simplest, although least efficient, approach to determining this set is to make it comprise the base station to which the mobile station is affiliated plus the list of base stations neighbouring it.

A more efficient approach would be to arrange for the mobile station to monitor the signal strength of the BCCH channels of the neighboring base stations and report the addresses of the two (or more) base stations providing the strongest signals. Alternatively, the mobile stations can simply report the actual BCCH signal strength and the receiving base station or the RNC can determine the basc stations to be involved. The BCCH signal strength can be measured by correlating against the appropriate mid-amble codes. Note that these measurements will be performed anyway to support the hand-over decision process.

Once the set of base stations involved has been determined, the schedules for synchronisation measurements can be established for each base station. The procedure is then identical to that described previously for normal synchronisation. The mobile station is also instructed to make, at a suitable time, a transmission at full power on the RACH using, preferably, the same burst structure as defined earlier for inter base station transmissions. The time for this transmission should be close to the transmission times for the inter base station sync transmission in order to minimise the effect of clock drift. However, the mobile station transmission may be before, interspersed with or after the inter base station sync transmissions. In a preferred implementation the RNC will select the schedule for the mobile station to make its transmission. This will be signalled to the mobile station on a suitable signalling channel by the base station to which it is affiliated. Other means of scheduling are not precluded. The RNC will also instruct the base station involved to signal, preferably in their BCCH channel to their affiliated mobile stations that that particular RACH time slot is unavailable for random access transmission.

Alternatively, this prohibition may be restricted to the base station to which the mobile station is affiliated. The rationale for this is that the mobile

is transmitting at full power and so can easily reach the base station at the centre of its own cell with enough power to make RACH reception impossible. However, the range to the other base stations will typically be greater than the range from any mobile station attempting a RACH within those cells. Since the latter will use power control, it should be possible for the processing gain between the various codes to facilitate simultaneous reception.

The three (or more) base stations will each receive the signal from the mobile station and compare the reception time with their own timing. Given that the positions of the base stations will be known this will provide all of the information needed to locate the mobile station.

If, following any of the various transmissions required to support positioning, either inter base station sync transmissions or the transmission from the mobile station, any of the measurements have not been adequately received, the RNC can schedule repeat transmissions as necessary, either to facilitate computation of the position or to improve its accuracy.

So far the discussion of synchronisation has covered only fine sync after coarse synchronisation has already been achieved.

With an RNC in control, initial synchronisation can be achieved in a straightforward manner. When a network is commissioned the base stations may be activated in sequence either by manual intervention or under control of the RNC. The first base station to be activated becomes the temporary timing master and makes periodic sync burst transmissions in its RACH channel. Other base stations, activated later are only allowed to transmit after they have received a sync burst. In this way the network will become synchronised globally. If an individual base station requires re-synchronisaton, for example, following a failure and repair then, again it is not allowed to transmit until it has received a RACH channel synchronisation

burst from at least one other base station. It may then make its own RACH channel burst transmission, after making a coarse update to its timing from the initial burst.

The above achieves slot and frame synchronisation since the RACH slot is in a fixed position within the frame. Multi-frame synchronisation can be achieved by a number of means. The simplest and preferred method is to make the RACH slot which is 'stolen' for synchronisation always be contained in the first frame or any fixed arbitrary numbered frame within a multi-frame.

None of the above description precludes the incorporation of base stations equipped with a GPS receiver. In this case, the compensation values for those base stations are set equal to zero and the constraint that the sum of compensation values equals zero is removed. In this way, the synchronisation scheme will cause all of the base stations involved to become synchronised either directly or indirectly to GPS.